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MONITORING PONDEROSA PINE DECLINE AND MORTALITY ON THE FLATHEAD INDIAN RESERVATION
Establishment Report and 5-Year Results

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INTRODUCTION

Mortality in ponderosa pine from annosum root disease (*Heterobasidion annosum* (Fr.) Bref) was first diagnosed on the Flathead Indian Reservation (IR) in the mid 1970's (Williams and Haglund 1976; see Appendix for biology of annosum root disease). Extensive root disease and/or drought symptoms and associated mortality were recognized in the Dry Fork area and nearby Sunrise area on the Reservation's west side in the late 1980's, and appeared to increase significantly in 1990. Mature pines scattered throughout that area had been dying at an unknown rate. Many crowns were thin, with needle retention lower than expected; terminal growth was poor; and in some cases, foliage color was chlorotic or appeared to have a silver cast. Annosum root disease had been identified as a causal agent in some of these situations.

In 1993, we established permanent plots to monitor the decline of ponderosa pine on the west side of the Flathead IR. The main objectives of the study were: (1) determine rate of decline of individual trees; (2) identify symptoms which can be used to predict time of mortality; and (3) determine mortality rate over time. All of these objectives will help the Tribes manage their ponderosa pine. Large ponderosa pine have great significance to tribal members, but economics dictate harvesting of trees before they die to optimize monetary value. We also hoped to determine the overall cause of decline and mortality.

METHODS

Plot Selection

We investigated the possibility of using annual aerial videography to monitor mortality with the Methods Application Group (MAG), Fort Collins (now called Forest Health Technology Enterprise Team, Fort Collins). We determined aerial video technology was too much in its infancy to use as the main survey tool. MAG considered using this project as a test site for the usefulness of aerial videography to monitor annual mortality, so we attempted to design ground plots to compliment a future aerial video test project.

We created a random number list using UTM coordinates from the IR's west side under 4,400 feet elevation (R24W and T19N north to T24N). This general area was selected by Tom Corse, IR forester, as the area of most concern.

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We selected the first 23 UTM coordinates from the random number list and then delineated ¼-mile wide flight lines on 1:24,000 topographic maps. Each flight line was drawn from the selected UTM coordinate north to the next UTM coordinate. The first 18 flight lines that were entirely on IR land, were forested, and mostly under 4,400 feet elevation were then selected for aerial photography.

In June 1993, these 18 flight lines were flown and 1:6000 aerial photography was taken. Three flight lines were discarded because they were in an active timber sale (Welcome Springs), which left 15 flight lines.

The photo which best represented each flight line was selected. A scaled overlay which represented an 8-acre transect 264 feet wide (east/west) by 1,320 feet long (north/south) was placed over each photo to delineate ground sampling. Starting point for each transect was the south end of overlay. Each photo was then pinpricked and the spot was located on the ground. Ground transects ran due north for 1,320 feet from starting points. Rebar was placed at starting and ending points on all transects, and reference trees were painted and tagged with an aluminum tag at approximately 4.5 feet above ground. Starting points were located on maps and photos, along with directions for locating them. Transects were established in 1993.

At the time of plot establishment, the Tribes requested we include a transect in an area of known annosum infection. They selected the site and we verified the presence of annosum fruiting bodies on the roots of overstory trees and seedlings/saplings. The Tribes located this non-randomly selected transect (Annosum transect) adjacent to the leading edge of an active *H. annosum* root disease center. This transect was not flown and was analysed separately.

Data Collected

At plot establishment, all trees 15 inches or greater in diameter at breast height (d.b.h.) within boundaries were tagged at the base with an aluminum numbered tag. Their general location was also noted on a transect grid map. Crowns of all trees were given a numerical rating for needle complement, needle length, needle color, and twig and branch condition. The highest cumulative rating a crown could receive was 9 (Table 1). A high rating indicated a tree in poor condition. This rating system was based on risk rating systems developed for predicting mortality of ponderosa pine from bark beetles (Salman and Bongberg 1942) and oxidant air pollution (Miller 1973).

Table 1. Ponderosa pine crown rating system.

SYMPTOMS	RATING
1. Needle Complement	
a. normal (3+ years retention)	0
b. 2-year needle retention	1
c. 1-year needle retention (bottle brush)	2
2. Needle Length	
a. normal	0
b. shorter than normal throughout crown	1
c. needles shorter in upper crown, normal below a definite contrast	2
3. Needle Color	
a. normal	0
b. off color (moderately chlorotic)	1
c. fading, more yellow than green	2
4. Twig and Branch Condition	
a. no twigs or branches dead	0
b. a few scattered dead or dying branches or twigs in crown, with <10% occurring in uper ½ of crown	1
c. 10-20% of twigs and branches in upper of crown dead	2
d. greater than 20% of twigs and branches inupper ½ of crown dead	3
CUMULATIVE CROWN RATING : TOTAL POSSIBLE	9

The following information was also collected and recorded for each tree: d.b.h., crown ratio, crown class, and damages using Region 1 Timber Stand Exam damage codes (Anonymous 1985: 415.4-415.51). A standard stand exam plot (Anonymous 1985) was then nested on the transect center line at three locations: 264, 660, and 1,056 feet from each starting point. A variable-radius plot using 10 BAF (basal area factor) was used to tally trees 5 inches d.b.h. and larger, and a nested 1/100-acre fixed plot was used to count regeneration and estimate ground coverages.

In addition to the above data, an informal survey was done on each transect looking for the presence of *H. annosum*. Cut stumps were investigated for typical decay and/or fruiting bodies, and seedling and sapling mortality was checked for presence of button conks. When possible, mortality trees were sampled to determine the presence of *H. annosum*. Dead trees were cut and 2-inch thick discs were taken as close to ground level as possible and incubated in a moisture chamber to verify the presence of the asexual stage of the fungus, *Spiniger meineckellus* (A.J. Olson) Stalpers.

Transects were revisited each year, except 1997, when time and financial constraints prevented a remeasurement. Mortality was recorded at these annual visits, as well as any significant changes. In 1998, in addition to mortality, crowns of all live tagged trees were rated again and damages were again recorded. Any missing tags were replaced, and reference trees were repainted as necessary.

Statistical Analysis

One-way analysis of variance was used to test for significant differences between live and dead trees. T-tests for paired samples were used to test for significant differences between 1993 measurements and 1998 measurements of live trees (SPSS 1994).

RESULTS

Transect Characteristics

Fifteen randomly selected transects were established during 1993 for a total of 751 live tagged trees. Transect 4 was burned in the 1998 Boyer Wildfire and was excluded from further analyses. See figure 1 for transect locations. All transects are under 4,400 feet elevation, with a wide variety of slopes, aspects and habitat types. See table 2 for transect characteristics.

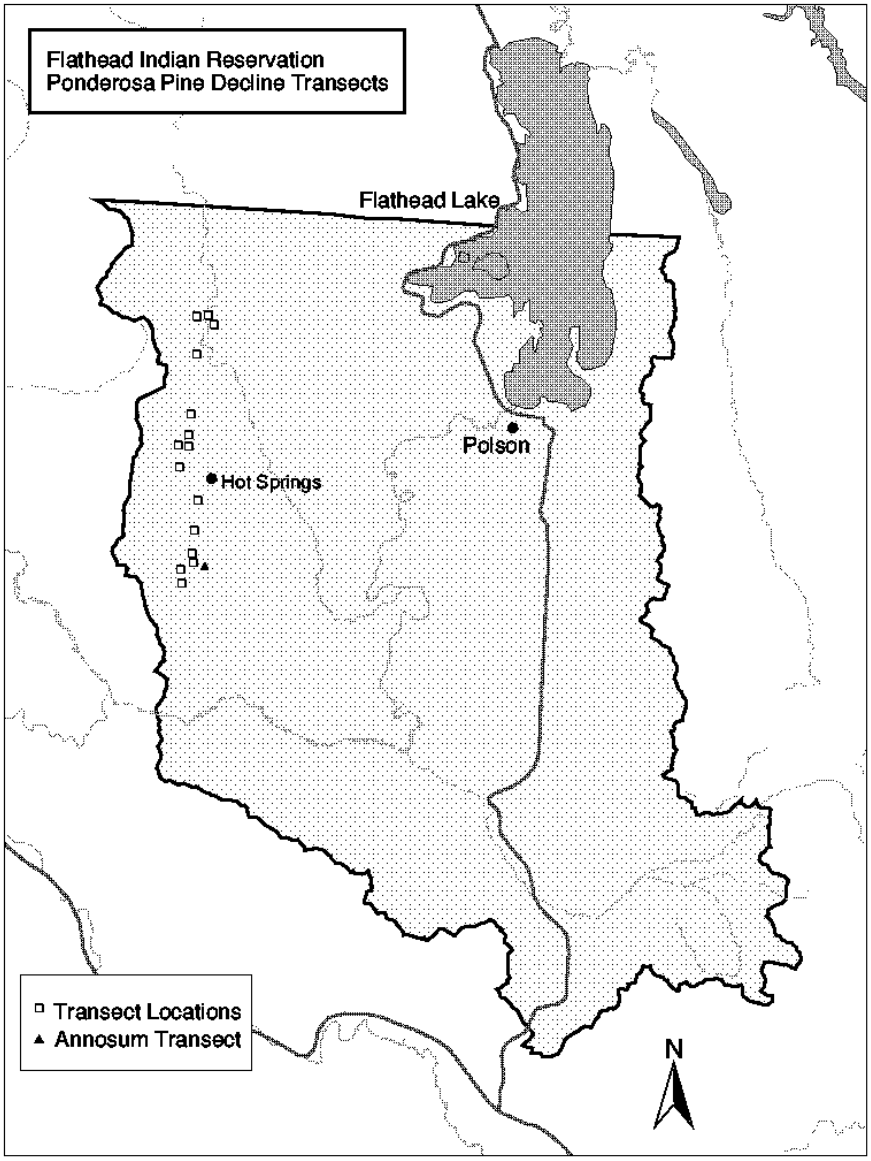

Figure 1. Map of transect locations on Flathead Indian Reservation.

Table 2. Transect characteristics at time of plot establishment.

Transect #	Elevation (feet)	Slope (%)	Aspect	# Ponderosa Pine Trees >=15.0"d.b.h.	1993 Average d.b.h. (inches)	Average BA[1] for all trees	*H.annosum* confirmed on the transect	Habitat Type[2]
1	3600	26	S	63	22.5	118	No	ABGR/XETE (510)
2	3600	20	N	48	20.3	91	No	ABGR/LIBO/LIBO (591)
3	4000	25	N	43	19.9	75	No	PSME/VACA (250)
4[3]	3600	30	E	48	23.0	67	No	ABGR/LIBO (590)
5	3800	40	N	31	21.7	84	No	PSME/VACA (250)
6	3400	27	W	46	19.8	46	Yes	PSME/SYAL/AGSP (311)
7	4200	8	N	87	27.2	121	Yes	PSME/VACA (250)
8	3900	20	E	25	19.8	43	No	PSME/VACA (250)
10	4200	12	N	72	25.7	93	No	PSME/VACA (250)
11	3700	16	NE	78	21.4	63	Yes	PSME/VACA (250)
12	4100	25	S	43	21.2	107	No	ABGR/LIBO (590)
13	4200	30	NE	48	19.2	88	No	PSME/CARU (350)
14	3800	39	E	39	21.1	69	No	PSME/PHMA (260)
15	4000	14	N	66	19.5	61	No	PSME/CAGE (330)
17	4100	25	N	14	19.9	147	No	ABGR/LIBO/LIBO (591)
TOTAL	58,200			751				

[1] BA= square feet of basal area per acre.
[2] Series/Habitat Type/Phase (Pfister et.al. 1977).
[3] Transect 4 was burned in the 1998 Boyer Wildfire and was excluded from further analyses.

Crown Conditions

Average cumulative crown rating for all tagged trees at time of transect establishment was 1.8. When live trees were rated again 5 years later, cumulative crown rating significantly improved to 1.6 ($p<0.001$). Two of the individual crown characteristics also significantly improved (average needle complement, $p<0.001$; average needle length, $p<0.01$). Average twig/branch mortality significantly worsened ($p<0.05$) and there was no change in needle color from 1993 to 1998. Trees put on significant diameter growth over the 5 years; average d.b.h. increased from 21 inches to 22.4 inches (Table 3).

Table 3. Average crown characteristics for trees alive in 1993 and 1998 on randomly selected transects (excluding Transect 4).

Crown Characteristic	1993 Average Value (SE[1])	1998 Average Value (SE[1])	Trend (p value)
Needle Complement	0.37 (0.020)	0.19 (0.016)	Improved* (p<0.001)
Needle Length	0.19 (0.020)	0.14 (0.018)	Improved* (p<0.01)
Needle Color	0.02 (0.007)	0.02 (0.006)	No Change
Twig/Branch Mortality	1.20 (0.020)	1.25 (0.021)	Worsened* (p<0.05)
Cumulative Crown Rating	1.79 (0.048)	1.61 (0.046)	Improved* (p<0.001)
D.B.H.	21.92" (0.201)	22.42" (0.203)	

[1] SE = standard error of the mean
* significantly different

Other Damages

Three damages were recorded for each tagged tree. Table 4 lists the five most common agents recorded for all transects and their frequencies.

Table 4. Most common damages recorded for live trees at plot establishment.

1993 Damage	Frequency
Fork/crook/sweep	323
Western gall rust[1]	217
Logging wound	87
Fire scars	67
Elytroderma needle blight[2]	57
No damage	311

[1] Western gall rust = *Endocronartium harknessii* (Moore) Hirat.
[2] Elytroderma needle blight = *Elytroderma deformans* (Weir) Darker

The most common biological damaging agent recorded was western gall rust (*Endocronartium harknessii* (Moore) Hirat.). Over 21% of trees had western gall rust recorded as a damaging agent. The second most common biological damaging agent recorded was Elytroderma needle blight (*Elytroderma deformans* (Weir) Darker). Almost 6% of all live trees had Elytroderma recorded as a damaging agent.

In addition to the above damaging agents recorded for each tree, *H. annosum* was confirmed on 20% of transects.

Mortality

In 1994 (year 1), one tree was killed by secondary bark beetles and tested positive for *H. annosum*. In 1995 (year 2), one tree was killed by a combination of lightning and secondary bark beetles, and two trees were salvaged after death so cause of mortality could not be confirmed, but was assumed to be bark beetles. Samples were collected from the lightning killed tree and the stumps of the two salvaged trees, but *H. annosum* was not confirmed. No trees died in 1996 (year 3). In 1997/1998 (years 4 and 5), one tree was killed by western pine beetles and two trees were lost to road improvement and harvesting. Samples were not collected from these three trees.

Transect 4 was burned by the Boyer Wildfire during the 1998 fire season. Seven trees on the transect were killed outright by the fire. Although many trees survived, the transect was

no longer useful for this project, so the 1998 remeasurement for transect 4 was dropped from the analysis.

Over the 5-year period, 14 trees died from various causes: seven trees were lost to fire; two trees were lost to harvesting and/or road improvement; and five trees died from "natural" causes other than fire. The latter five trees were the only trees we could use to calculate a representative mortality rate. Average annual mortality was 0.14% for ponderosa pine trees 15.0 inches d.b.h. or greater. See Table 5 for a summary of mortality.

Table 5. Individual mortality characteristics and probable cause .

Year of Mortality	Tree ID[1]	1993 D.B.H. (inches)	1993 Cumulative Crown Rating	Cause	Presence of *H. annosum*
1994	7-270	25.5	8	Beetles	Yes
1995	7-278	35.4	2	Salvage/beetles?	No
1995	8-471	23.9	1	Lightning/beetles	No
1995	10-416	27.4	8	Salvage	No
1997/98[2]	4-290	19.0	1	Fire	Not sampled
1997/98	4-458	29.6	2	Fire	Not sampled
1997/98	4-463	35.6	3	Fire	Not sampled
1997/98	4-467	29.3	2	Fire	Not sampled
1997/98	4-466	26.2	3	Fire	Not sampled
1997/98	4-515	16.6	4	Fire	Not sampled
1997/98	4-521	21.9	1	Fire	Not sampled
1997/98	10-426	22.4	5	Beetles	Not sampled
1997/98	12-709	26.3	2	Harvested	Not sampled
1997/98	12-715	15.0	0	Road Improvem.	Not sampled

[1] Tree ID=Transect number - tree number.
[2] Mortality in shaded rows were not included in calculating mortality rate nor decline symptoms tied to mortality.

When 1993 average crown characteristics of trees that died over 5 years were compared to trees that lived over 5 years, they were found to be significantly different. All crown ratings were statistically greater (worse) for trees that died (Table 6). Additionally, trees that died were significantly larger in d.b.h. than trees that survived (26.9 inches and 21.92 inches, respectively; $p<0.05$).

Table 6. 1993 average crown characteristics for trees dead through 1998 and 1998 live (excluding Transect 4).

Crown Characteristic	Dead Tree Average Value (SE[1])	Live Tree Average Value (SE[1])	Significance
Needle Complement	1.20 (0.490)	0.37 (0.020)	p<0.001
Needle Length	0.80 (0.374)	0.19 (0.020)	p=0.01
Needle Color	0.60 (0.400)	0.02 (0.007)	P<0.001
Twig/Branch Mortality	2.20 (0.490)	1.20 (0.020)	p<0.001
Cumulative Crown Rating	4.80 (1.463)	1.79 (0.048)	p<0.001
D.B.H.	26.9" (2.277)	21.92" (0.201)	p<0.05

[1] SE = standard error of the mean

Annosum Transect

This transect was selected by the Tribes based on the presence of *H. annosum*. Table 7 lists the transect characteristics.

The non-randomly selected Annosum transect was analyzed separately, but similarly to other transects. Average crown characteristics consistently worsened over 5 years, although only three measurements were statistically significant: needle color, twig/branch mortality and cumulative crown rating (Table 8). The average d.b.h. increased from 18.9 inches to 19.9 inches over the 5 years.

Table 7. Annosum transect characteristics at time of plot establishment.

Elevation (feet)	**Slope (%)**	**Aspect**	**#Ponderosa Pine Trees >=15.0"d.b.h.**	**1993 Ave. d.b.h. (inches)**	**Average BA[1] for all trees**	***H.annosum* confirmed on the transect**	**Habitat Type[2]**
3200	10	SE	255	18.9	100	Yes	PSME/SYAL (310)

[1] BA= square feet of basal area per acre.
[2] Series/Habitat Type/Phase (Pfister et.al. 1977).

Table 8. Average tree characteristics for trees alive in 1993 and 1998 on Annosum Transect only.

Crown Characteristic	**1993 Average Value (SE[1])**	**1998 Average Value (SE[1])**	**Trend (p value[2])**
Needle Complement	0.11 (0.020)	0.12 (0.024)	Worsened (NS)
Needle Length	0.04 (0.013)	0.06 (0.017)	Worsened (NS)
Needle Color	0.01 (0.006)	0.05 (0.015)	Worsened* (p=0.01)
Twig/Branch Mortality	1.06 (0.018)	1.20 (0.030)	Worsened* (p<0.001)
Cumulative Crown Rating	1.22 (0.037)	1.43 (0.065)	Worsened* ((p=0.001)
D.B.H.	18.86" (0.216)	19.90" (0.323)	

[1] SE = standard error of the mean
[2] NS = not significant at p<= 0.10
* significantly different

Only one tree died over 5 years, and it occurred in 1994 (Table 9). The tree had been hit by lightning at time of plot establishment and was attacked by western pine beetles (*Dendroctonus brevicomis* LeConte) the following year. In 1994, we collected a 2-inch thick disc at ground level which tested positive for *S. meineckellus*. Death of one tree on this transect equates to an average annual mortality rate of 0.08%. Because only one tree died, a comparison of crown characteristics of trees that lived versus trees that died was not made.

When the non-randomly selected Annosum transect was compared to the 14 randomly selected transects, trees on the Annosum transect were significantly smaller in d.b.h. and average crown characteristics were significantly better than trees on the other transects (Table 10).

Table 9. Individual mortality characteristics and probable cause .

Year of Mortality	Tree ID[1]	1993 D.B.H. (inches)	1993 Cumulative Crown Rating	Cause	Presence of *H. annosum*
1994[2]	SS-163	20.8	1	Lightning/beetles	Yes

[1] Tree ID=Transect number - tree number. (SS=Annosum Transect)

Table 10. 1993 average live tree characteristics for the non-randomly selected Annosum Transect compared to the 14 randomly selected transects at plot establishment.

Crown Characteristic	1993 Average Value (SE[1]) Annosum Transect	1993 Average Value (SE[1]) 14 Randomly Selected Transects	Significance
Needle Complement	0.11 (0.020)	0.37 (0.020)	$p<0.001$
Needle Length	0.04 (0.013)	0.20 (0.020)	$p<0.001$
Needle Color	0.01 (0.006)	0.03 (0.007)	$p<0.10$
Twig/Branch Mortality	1.06 (0.018)	1.21 (0.021)	$p<0.001$
Cumulative Crown Rating	1.22 (0.036)	1.81 (0.049)	$p<0.001$
D.B.H.	18.86” (0.216)	21.96” (0.201)	$p<0.001$

[1] SE = standard error of the mean

DISCUSSION

Overall, there was very little decline or mortality in ponderosa pine trees 15 inches or greater d.b.h. over the 5 years of this study. When all randomly selected transects were analyzed, crown characteristics generally improved. The exception was the characteristic of twig and branch mortality, which worsened. The appearance of a decline noted in the late 1980’s and early 1990’s was likely very real, but data from these transects indicate the mortality rate was low for the 5 years of this study (1993-1998). Mortality and decline rates may have been higher in previous years, and the period of this study did not capture those higher rates.

The appearance of an overall decline in the previous years may have been due to droughty conditions the area experienced in the late

1980's and early 1990's. Data from the National Climatic Data Center indicates a droughty period existed from 1986 through the second half of 1993, the year of plot establishment. At plot establishment in 1993, 3 of the previous 6 years experienced moderate drought and the remaining 3 years were barely within normal range, according to the Palmer Drought Severity Index (National Climatic Data Center 2000). Palmer Drought Severity Index ranged from –5.0 (severe drought) during 1987, to +1.0 (near normal) during 1989-91. During the 5-year time period of this study, precipitation for the area had returned to more normal levels, with 2 of 5 years falling in a "very moist spell" (Palmer Drought Severity Index = +3.0 to +3.9, or greater). Another period of drought in the future may initiate another appearance of decline.

Crowns of trees that died were significantly worse than trees that survived the 5-year time period. This indicates the rating system used in this study may have some predictive value. Individual crown characterisitics which are most predictive cannot be determined from this study due to the low mortality rate. A most predictive characteristic and threshold may be revealed over time.

Twig and branch mortality worsened over the study period. This general twig and branch decline may be due to varying levels of western gall rust and Elytroderma needle blight. Western gall rust was recorded on over 21% of all live trees in 1993, and Elytroderma needle blight was recorded on almost 6% of the trees. Western gall rust causes galls to form on infected branches or stems of trees. Branches and sometimes small stems are killed when insects and other fungi attack galled tissue (Byler et al. 1972). High levels of western gall rust in crowns of trees can cause significant branch mortality and possibly top kill (Peterson et al. 1960; Hennon 1993), contributing to an overall decline in the vigor of individual trees.

Elytroderma needle blight is considered the most important needle disease of pines in the Pacific Northwest (Childs et al. 1971). It is most damaging in trees of low vigor with poor crowns, however, the disease is often more conspicuous in good crowns. In larger trees, direct mortality from Elytroderma is uncommon, but infection contributes to permanent deterioration of crowns and consequent reduction of growth and increase in vulnerability to bark beetles, root diseases and other enemies (Childs 1968; Childs et al. 1971). There is also some evidence to suggest that very droughty conditions, such as occurred in the area prior to plot establishment, hasten death of infected twigs (Childs 1968).

The addition of the annosum transect allowed some comparisons to be made between a known annosum-infected site with randomly selected sites. On the annosum transect, average crown characteristics consistently worsened from 1993 to 1998. This is contrary to randomly selected transects, where average crown characteristics consistently improved over the 5 years. It is possible that if we analyzed the randomly selected transects with confirmed annosum infection separately, we might see a similar trend to the non-randomly selected annosum transect. This warrants further investigation.

The 1993 crown measurements for the annosum transect were statistically better than the randomly selected transects. The trees on the annosum transect are smaller and appear to be younger (data not analyzed), so they have not been exposed to damaging agents for as long as trees on the other transects. It is noteworthy that trees on the annosum transect have healthier crowns than trees on the randomly selected transects, but showed a general crown decline over 5 years, rather than an improvement in crown conditions as found on the randomly selected transects.

FUTURE PLANS

We plan to monitor these transects for another 5-year interval, at which time their usefulness will be assessed.

ACKNOWLEDGEMENTS

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APPENDIX

Identification and Biology of Annosum Root Disease

Annosum root disease is a white root and butt rot of many conifer species throughout western United States and many other temperate forest ecosystems (Hodges 1969). It is caused by the fungus *Heterobasidion annosum* (Fr.)Bref.. Symptoms of annosum root disease are similar to other root diseases. Infected trees may have faded, chlorotic crowns, reduced growth, stress-induced cone crops, resin at the base, resin-soaked and discolored wood, and decay in roots and butts. Annosum root disease can be identified by its fruiting bodies, characteristic decay it causes, and by isolating *H. annosum* from the associated incipient decay.

H. annosum fruiting bodies (i.e., sporophores or conks) can sometimes be found inside decayed hollowed stumps, just under the duff layer at the base of infected pines. It may also be found as small "button conks" on the outside of infected roots and root collars on all susceptible species. Annosum fruiting bodies are perennial, woody to leathery, with dark brown upper surface and white to cream-colored lower surface with very small pores. "Button conks" are small, corky mounds of sterile tissue, and are generally cream colored (Hagle et al. 1987).

Annosum decay varies, but is generally recognized in its early stage as a stain in the outer heartwood, which can be readily seen in a cross section of a freshly cut stump. The advanced decay is often white to yellow, stringy to laminate, and may contain white pockets with black flecks (Schmitt et al. 1984, Hagle et al. 1987). Positive identification of the decay can be made by culturing and/or incubating decayed wood and observing the imperfect stage of the fungus, Spiniger meineckellus (A.J. Olson) Stalpers.

H. annosum in western North America consists of two intersterility groups or biological species. These two types,'s' and 'p', have very different host specificities. Hosts for the p-type include pine species, incense cedar, and western juniper. The hosts for the s-type include true firs, giant sequoia, spruce, western hemlock, and Douglas-fir. This host specificity is not apparent in stump infections; both groups have been isolated from "non-host" stumps without causing disease in neighboring "host" trees (Lockman 1993, Otrosina et al. 1992, Kliejunas 1986). In intermountain forests, butt rot is associated with infection in spruce and true firs, and outright tree mortality is more common in pines and Douglas-fir (Hagle 1985, Byler and Hagle 1985). Infected trees often are attacked by bark beetles (Byler 1989, Ferrell and Parmeter 1989, Hadfield et al. 1986).

Annosum root disease can spread in several ways. *H. annosum* in a diseased tree can infect a healthy neighboring tree by ectomycelium growing across root contacts, if the neighboring tree is a susceptible species. *H. annosum* can also spread by airborne spores (Hodges 1969, Hsiang et al. 1989). When spores land on a newly cut stump or fresh basal wound, they may germinate and colonize the wood if conditions are favorable. Spore infections are usually limited to the tops of freshly cut stumps in pine

species (Otrosina and Cobb 1989), while freshly cut stumps and fresh basal wounds are susceptible to infection in other species (Schmitt et al. 1984). The newly infected stump or tree may then initiate a new disease center by root-to-root contact.

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